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# Report

## AN ADVANCED TEST SYSTEM FOR THE CHARACTERIZATION OF AEROSPACE MATERIALS IN SEVERE SERVICE ENVIRONMENTS

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Mr. Norman D. Schehl

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Structural Integrity Division
Integrated Methods Material Characterization Group
300 College Park
Dayton, OH 45469-0120

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# AN ADVANCED TEST SYSTEM FOR THE CHARACTERIZATION OF AEROSPACE MATERIALS IN SEVERE SERVICE ENVIRONMENTS

Final Report

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Prepared by:

Norman D. Schehl

STRUCTURAL INTEGRITY DIVISION
Integrated Methods Material Characterization Group
300 College Park
Dayton, OH 45469-0120

## ABSTRACT

A unique, advanced test system for the characterization of materials was designed and assembled. The test system is capable of simulating the mechanical, thermal, vacuum and variable atmospheric environments that high performance aerospace materials are subjected to during service. Details of the design, optimization, and performance testing of this system are described.

## FOREWORD

The construction of the research tool described in this final report was conducted under Air Force Office of Scientific Research (AFOSR) Grant No. F49260-95-1-0498. The purpose of the program was to put in place at the University of Dayton Research Institute a material test system capable of simulating mechanical, thermal, and atmospheric service environments typical of the environments experienced by current and 21st century high-performance aerospace materials. The test system will allow mechanical, thermal and atmospheric loadings to be simultaneously imposed and synchronized as in traditional in-phase (IP) and out-of-phase (OP) thermomechanical fatigue (TMF) testing. By applying arbitrary mechanical, thermal, and/or atmospheric loading histories, this system is also capable of simulating service histories such as mission cycles for turbine engines, hypersonic structures, and advanced propulsion system components.

In addition to applying the anticipated service environmental loads, acquisition of material response data is equally important to understanding material behavior. Provisions for extensive data acquisition instrumentation including *in situ* ultrasonic NDE techniques have been incorporated in the design.

Based on our previous work, we established the following performance goals for the system:

| | |
|---|---|
| Mechanical loading - | ± 50 kN @ 0 to 50 Hz |
| Thermal range - | - 100°C to over 1500°C dynamic |
| Atmospheric - | $10^{-9}$ to 100 Torr plus 10 to 1000 Torr inert gas |
| Pump-down time - | < 1 hour to $10^{-8}$ Torr with full test setup |

The enhanced capabilities that this system offers over existing systems will be instrumental in the education of graduate level university students. This system will also dramatically improve the material characterization capabilities of the University for research involving DOD, industry, and educational programs.

Included in this report are details describing the experimental methodologies which must be addressed in planning such a system. In addition, descriptions of the many subsystems which make up this sophisticated materials characterization instrument and how they influence the systems overall performance are provided.

The construction of this advanced materials characterization test system benefited from the contributions of many members of the UDRI team including, George A. Hartman, David A. Stubbs, Andrew H. Rosenberger, and Norman D. Schehl. Contributions made in the form of technical expertise by Irwin Richman of Advent Associates were also greatly appreciated.

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# Section 1
## *Introduction*

State of the art materials, implemented in advanced aero-structures and propulsion systems, are subjected to severe service environments. Service histories such as turbine engine mission cycles, hypersonic airframe structures, and advanced propulsion systems all include conditions combining mechanical and thermal stresses in varying atmospheres [1]. To accurately characterize the mechanical behavior of components subjected to these service histories, the researcher needs to identify the fundamental damage modes in the materials and the individual contribution of mechanical loads, thermal stresses, and surrounding atmospheres as well as the synergistic effects of combined-mode damage. The understanding of damage mechanisms in advanced materials and prediction of their expected performance in a given service environment requires essential information about damage accumulation under a variety of conditions. Facilities exist to simulate time-varying mechanical, thermal, and atmospheric environments, however, the simulation of all three of these variables in a dynamic mode is extremely limited.

The University of Dayton Research Institute (UDRI) set about acquiring components of and constructing a material test system capable of simulating the mechanical, thermal, and atmospheric service environments typical of current and 21$^{st}$ century high-performance aerospace service histories. Due to the complexity and unique nature of this research tool, a complete system was not available as a package from a single commercial vendor, rather, the system is a combination of the best technologies available for the simulation of service environments as well as monitoring of material damage. Commercial components were used wherever possible to minimize costs, and specialized components were used only where they had the greatest impact on overall capability and quality of test results. The advanced test system assembled under this contract (including atmospheric environmental control) is a natural extension of our existing systems which have the capability for dynamic control of both mechanical and thermal conditions for TMF testing.

The test system allows mechanical, thermal, and atmospheric loadings to be simultaneously imposed and synchronized as in traditional in-phase (IP) and out-of-phase (OP) thermo-mechanical fatigue (TMF) testing. In addition, the test system is capable of applying arbitrary mechanical, thermal, and/or atmospheric loading histories as a function of time. The enhanced test system has a load capacity of ±50 kN, a temperature range of -100 °C to over 1500 °C, and atmospheric simulation from 1.0E-9 Torr vacuum to 1000 Torr, plus 1 to 1000 Torr inert gas or laboratory air. A multiple-zone quartz-lamp heating system is used to produce either extremely uniform spatial temperature fields (under both static and thermal cycling conditions) or specified thermal gradients within the specimen under test. Specialized grips are used to ensure accurate alignment and uniform clamping forces on specimens. Coupled within the severe

environment simulation are non-destructive evaluation (NDE) techniques which will enable the researcher to observe the ultrasonic and acoustic emission signals produced by the subject specimen. These signals have been shown to be of great value in evaluating the state of damage in the material.

This report is organized in sections detailing each subsystem that makes up the severe environmental simulation system including the mechanical test frame, the environmental chamber and atmospheric simulation equipment, the thermal simulation equipment, and the instrumentation for data collection of both the simulated conditions and NDE.

# Section 2
## *System Components*

### 2.1 Mechanical Loading System

2.1.1 Mechanical Test Frame

The most fundamental structure of the advanced test system is the frame used for inducing mechanical stresses in the specimen. The load frame used in this test system is an enhanced version of apparatus developed for the Air Force Materials Directorate by the University of Dayton as part of the effort under contracts F33615-91-C-6506 and F33615-94-C-5200. This load frame design is in use at a number of government, industrial, and academic laboratories. The load frame is extremely versatile for performing various tests including sustained load (creep), tension, fatigue, TMF, TMF crack propagation, low cycle fatigue (LCF) and high cycle fatigue (HCF). The load train is oriented in a horizontal plane resulting in superior spatial temperature stability during elevated temperature tests. This enhanced stability is due to the fact that with a horizontal load train the shortest axis of the specimen is presented for natural convection. In addition, the horizontal orientation allows the use of reduced extensometer mounting forces – a significant advantage in thin foil or ceramic/ceramic composite testing. Finally, the horizontal orientation (especially for a system with a vacuum chamber) is significantly more convenient for the operator to set up and use since all important components are at ideal working height.

The complete test system is depicted in Figure 1. The load frame is an enhanced version of the UDRI design currently used in several materials characterization laboratories. The most fundamental modification made was the overall enlargement of the post spacing and length. This was necessary in order to accommodate the environmental chamber. Analytical methods were applied to increase the load frame post spacing while maintaining the structural stiffness and strength. Accommodating the chamber required an increase in both platen and crosshead dimensions in order to match the mechanical stiffness of the UDRI design. This resulted in a slightly larger yet equally robust load frame, and a sturdy basis on which to build the severe-environment simulation system.

2.1.2 Servo-hydraulic Subsystem and Control

A standard commercially available servo-hydraulic subsystem and controller is used to apply the mechanical forces to the specimen. The MTS model 244.21 servo-hydraulic actuator, is operated by an MTS model 458 3-channel controller. The actuator provides ± 50 kN (11 kip) forces and incorporates an anti-rotation guide in the design to prevent unwanted torques on the

specimen. The use of the MTS servo-hydraulic subsystem and controller is a cost-effective and robust method that is well-supported by the commercial sector.

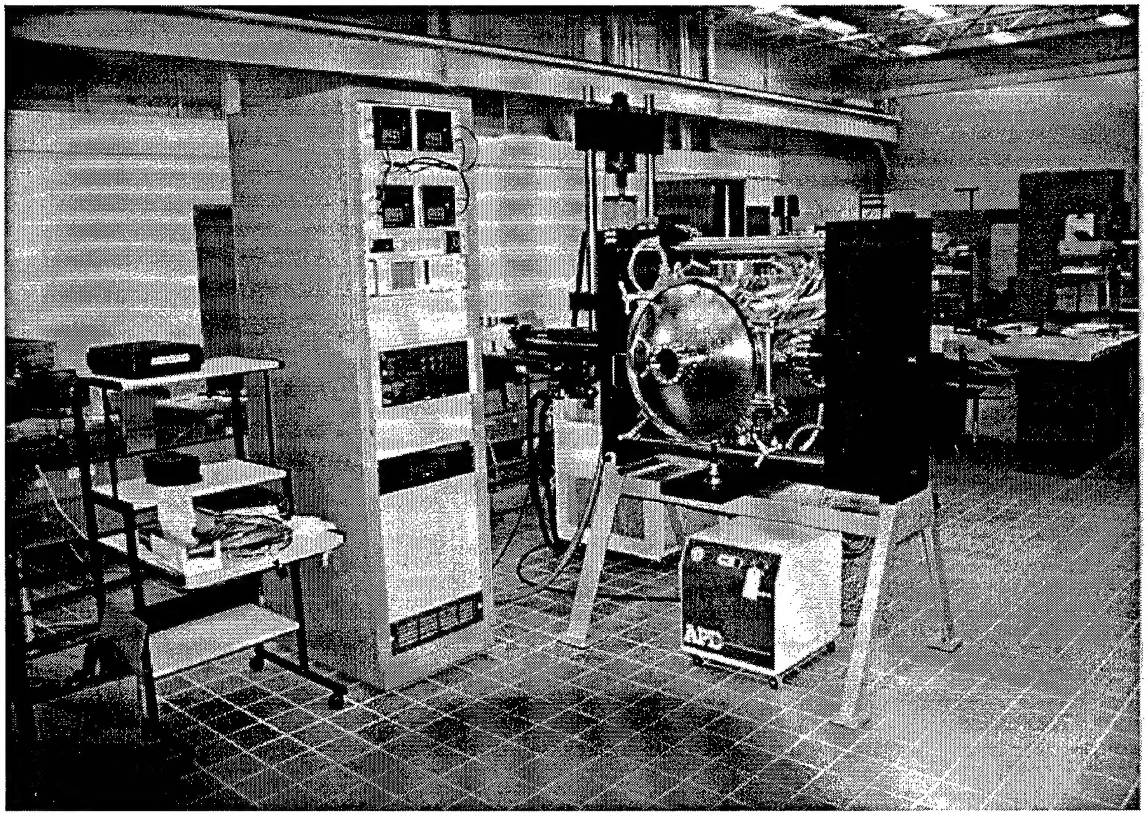

**Figure 1** Mechanical Load Frame and Assembled Severe Environment Test System.

2.1.3 Load Train Alignment

Proper alignment of the load train is crucial to the minimization of non-axial stresses in the specimen. Specimen misalignment will result in unacceptable bending stresses in the specimen invalidating the mechanical behavior results. A Wood's metal alignment method was adapted for use within the environmental chamber. The Wood's metal alignment fixture, machined from 304 stainless steel, is shown in Figure 2. Precision machined angles and grips are used to align the load train when the Wood's metal is melted. The Wood's metal then retains its precise location upon solidifying providing an accurately aligned load train. The application of Wood's metal differs from similar applications in that the retaining pot is configured horizontally. High temperature silicone rubber gaskets are used to retain the molten Wood's metal and provide the flexibility necessary to align the system.

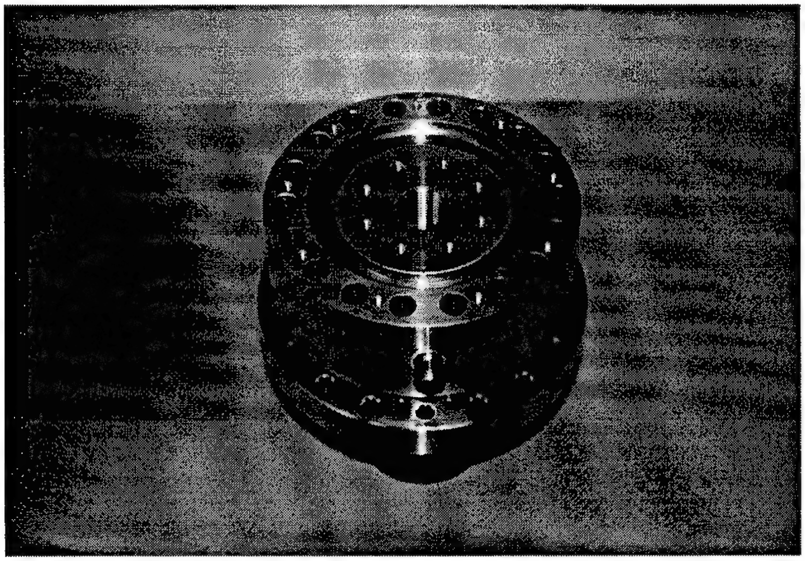

**Figure 2** Wood's metal Alignment System

2.1.4 Specimen Gripping

Integral to the alignment system are the specimen grips. The grip design was formulated keeping in mind the specimen geometries to be studied and the fact that the grips must perform in an ultra-high vacuum environment. The grips were fabricated from AerMet 100, an alloy which has exceptional strength, hardness and toughness, making it an ideal grip material. The grips were precision machined and ground for use with alignment angles. The grips are of a bolted grip configuration and clamping force is generated by means of torque applied to six bolts in each grip generating 45 kN of clamping force. The grips accept specimen widths up to 19 mm.

2.1.5 Force Measurement

In conventional environmental chamber systems, the load cell is placed outside the chamber and loads caused by the pressure difference across the chamber bellows must be measured and eliminated using the load conditioner zero control. It is possible to measure these pressure loads and correct for them under steady-state chamber pressure conditions. It is nearly impossible, however, to automatically adjust the servo-hydraulic system during pump-down/venting to maintain zero force on the specimen. Typically, the load zero is adjusted prior to pump-down so that the loads will be accurate during the test. This procedure results in typical tensile loads of 1 to 2 kN being placed on the specimen prior to pump-down. Many ceramic and CMC specimens cannot withstand this load without damage and, thus, cannot be tested in such systems.

An alternative to this arrangement is for the load cell to be within the environmental chamber such that the load cell measurement is a true reading unaffected by atmospheric pressure in the laboratory environment. This arrangement was used in the enhanced system by

incorporating a special stainless-steel encased load-cell located within the load train inside the environmental chamber. This placement allows the load cell to always record accurate specimen loads regardless of chamber pressure and avoids the problem of pressure-induced loads on the specimen during pump-down and venting. The closed-loop servo-hydraulic controls automatically correct for dynamic pressure loads because the load cell sees the same load as the specimen.

## 2.2 Vacuum / Inert Environment Simulation System

The Vacuum/Inert Environment chamber was designed for versatility and operation in the region of ultra-high vacuum (UHV) $10^{-9}$ to $10^{-11}$ Torr. The vacuum pumping system was chosen to minimize pump-down time so that test setup can be reduced to a more managable level than conventional systems. All of the components inside the vacuum chamber were designed using electropolished 300 series stainless steel to minimize corrosion and contamination. Special attention was given to the prevention and elimination of trapped gases and the minimization of component surface area.

### 2.2.1 Vacuum / Inert Environment Chamber

The Vacuum chamber was custom fabricated by MDC Vacuum Products. The chamber was constructed of 304 Stainless Steel, and electropolished to provide the clean surface finish necessary for UHV operation. The chamber was designed with a minimum of restrictions leading to the vacuum pump ports for optimal vacuum pump down even in the regions of molecular flow.

The chamber is attached to the mechanical test frame by means of a fixed bolted connection to the load frame crosshead. This novel attachment method maximizes the stiffness of the loading path to the specimen because it minimizes the specimen-to-crosshead load train length.

Because of the fixed chamber connection at the crosshead and the use of a load cell within the chamber, only one motion bellows was required. A welded stainless steel bellows was designed to provide coupling to the hydraulic actuator and a loading path to the specimen while maintaining UHV operation conditions. The bellows was specifically designed to allow the full range of actuator travel without over-extension damage when the actuator is fully extended or bellows crushing when the actuator is fully retracted.

To provide access to the chamber, several sizes of metal sealed UHV rated conflat flanges were included in the design. In total, there are twenty-five 2 ¾ inch feedthroughs, two 4½ inch feedthroughs, one 6 inch feedthrough and five 10 inch feedthroughs. These feedthroughs are radially spaced around the chamber to maximize the flexibility and provide expansion for future research. These feedthroughs are designed to accommodate auxiliary instrumentation, signal wiring to transducers, power wiring to the specimen heaters, gas and liquid cooling, optical view ports and the connection of the vacuum pumping or inert gas backfill systems. Although the

vacuum performance specifications detailed in this report were performed without heating the chamber to improve UHV performance, all flanges and chamber components are bakeable to 450°C for optimum vacuum performance.

Typical UHV chambers have complex metal sealed ports providing access to the chamber when not in use. The design of this chamber gave consideration to the extensive accessibility required within the chamber during specimen installation and preparation for testing. For these reasons, a large access door was highly desirable. The chamber design incorporates such a door as shown in Figure 3, however, rather than using a metal seal with numerous bolts, a dual o-ring seal is used. The dual o-rings are differentially pumped such that the differential pressure experienced by each o-ring results in a manageable rate of leakage. The outer o-ring is subjected to atmospheric pressure externally and a continuously roughed vacuum ($10^{-3}$ torr) internally, while the inner o-ring experiences the roughed vacuum as its external pressure and UHV internally. The pressure step down across the two o-rings enables the chamber to achieve UHV conditions without a metal sealing surface.

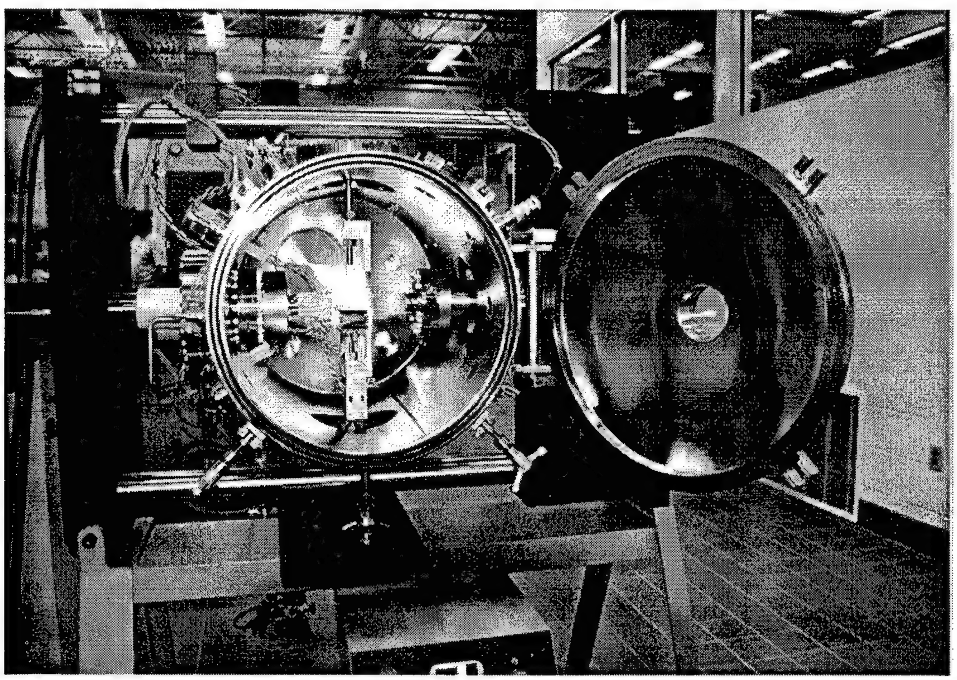

**Figure 3** Atmospheric chamber's differentially pumped front door.

### 2.2.2 Vacuum Pumping Stack

Minimizing pump-down time was an important consideration throughout the design of the vacuum chamber and environmental system. An oversize roughing pump stack was used toward this end. Although the oversize pumping stack does not compensate for excessive outgassing or large leaks in the chamber, careful chamber design reduced the effects of these issues to the

point of being negligible. In practice, the oversize stack dramatically reduces the time required to reach the desired vacuum for testing.

The vacuum pumping configuration is shown in Figures 4 and 5. The mechanical roughing pump chosen has a pumping capacity of 17 cfm, and is connected to; (1) the chamber for rough evacuation, (2) the differentially pumped front door for continuous operation, and (3) the UHV Cryopump for regeneration purposes. Each connection may be independently operated through the use of three electro-pneumatic metal sealed valves. A foreline trap was included in the pumping stack to absorb backstreaming hydrocarbons generated by the mechanical pump, and collect water vapor pumped by the rough vacuum.

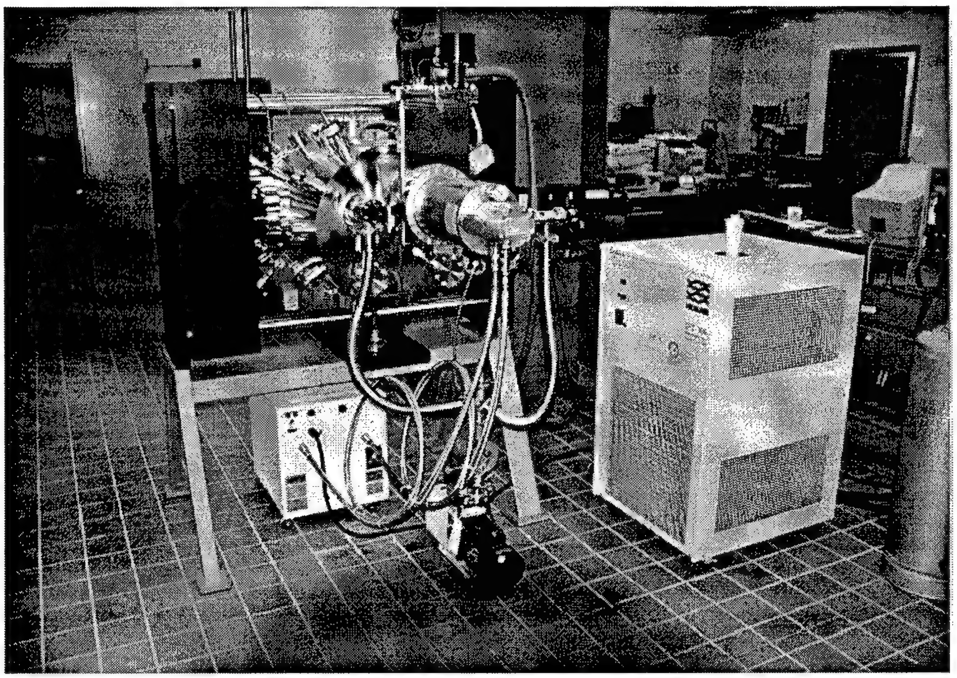

**Figure 4** Severe environment chamber UHV pumping stack.

An APD-8SC-UHV Cryopump was chosen for pumping in the regions below $1^{-3}$ torr. For this application, the cryopump was found to be superior to the more conventional high vacuum diffusion, ion, or turbomolecular pumps. The cryopump functions by freezing and adsorbing (capturing) gasses from the vacuum chamber. Because it has no moving or flowing components, it cannot contribute to contamination in the chamber. The cryopump operates like a freezer that accumulates large amounts of solid water and gasses such as air, nitrogen, and oxygen [2]. It is best at removing water from the chamber, and this is ideal for laboratory use where water contamination is often the most detrimental issue in a materials characterization test. The cryopump functions on the principle of a cryogenic helium expander that cools two, extended-surface cyropanels upon which gases freeze. The first stage expander and cryopanel operates in

the range of 50 to 75 K, and shields the colder, second-stage panel against radiant heat. Water is collected and frozen on the first stage panel, while the second panel operating at 10 to 20 K, freezes out nitrogen, oxygen and argon after they pass into the cryopump. A third collection device in the form of a charcoal filter adsorbs gasses that will not freeze at the second panel temperatures such as neon, hydrogen and helium.

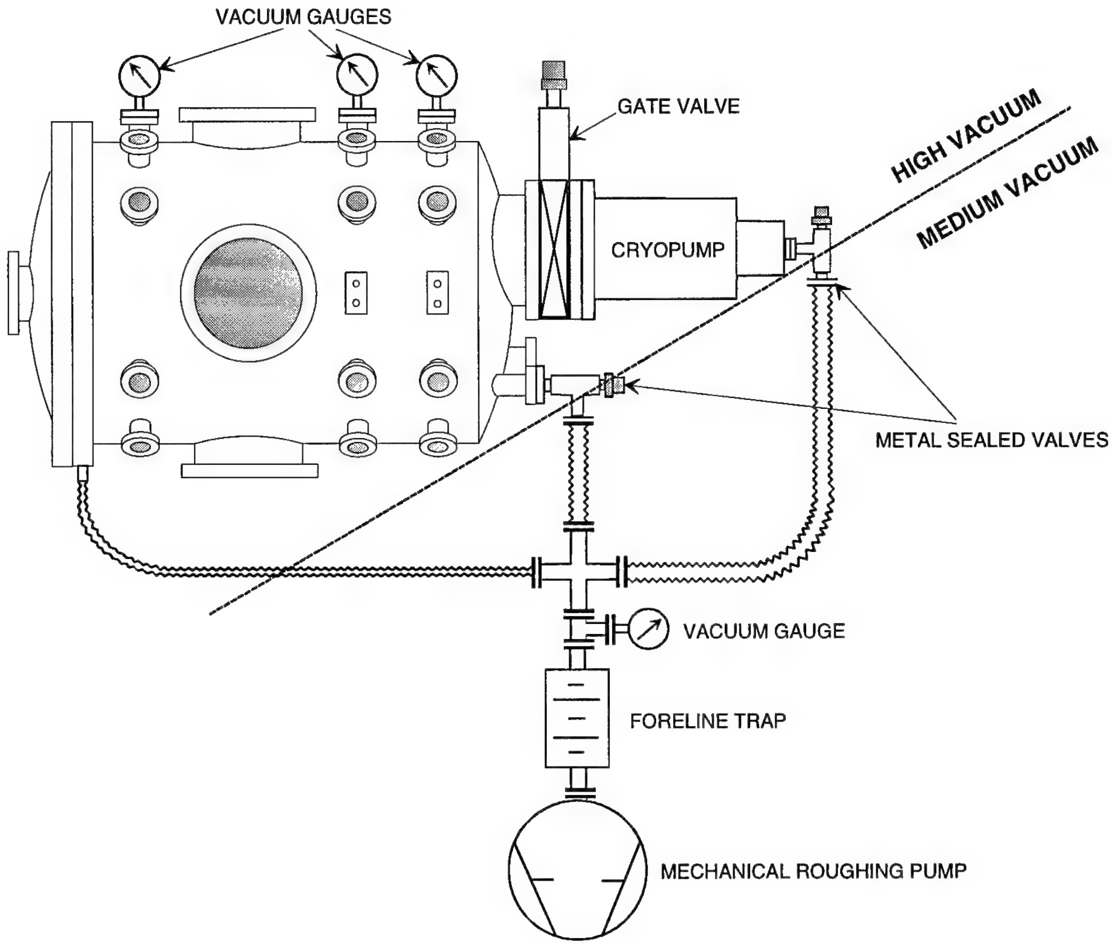


**Figure 5** Vacuum pumping stack and pressure measurement gages.

The cryopump is capable of pumping water vapor at a rate of 4200 liters/second to produce a clean fast vacuum into the realm of UHV. Occasional regeneration in the form of evacuating the cryopump with a rough vacuum is the only maintenance required. This low maintenance of all the pumping stack items is critical when the equipment is intended for use by graduate students with limited experience.

A metal sealed gate valve is used to separate the cryopump from the vacuum chamber. In the case of a power failure or sudden loss of vacuum in the chamber, the gate valves electro-

pneumatic operation protects the cryo-pump from exposure to atmospheric pressures while operating at cryogenic temperatures.

The vacuum pump-down procedure is as follows. First, all the electro-pneumatic actuated metal-sealed valves are closed while the roughing pump evacuates the pumping stack to a rough vacuum ($10^{-3}$ torr). The valves are then opened to the chamber and differentially pumped front door. Once a rough vacuum has been achieved in the chamber, the valve connection to the roughing pump is closed, and the gate valve opened exposing the cryogenically chilled baffles of the cryopump. This procedure has proven to provide an efficient and rapid pump-down sequence to Ultra-High vacuum ($10^{-9}$ torr).

### 2.2.2 Inert Gas Back-fill

It is often of interest to simulate test conditions which expose the specimen to a specific gas or atmospheric pressure condition. In addition to the vacuum capability of the chamber, this system can be controllably back-filled to a given proportion or pressure of a selected gas. A gas regulation and supply subsystem was developed to back fill the environmental chamber depending on the test to be performed. UDRI has prior experience using helium, nitrogen and argon which provide a non-aggressive atmosphere. The use of inert gasses at near-atmospheric pressures also allows us to perform TMF testing with forced convection cooling in an inert atmosphere.

An all metal gas leaking valve was selected for use with the back-fill system. The valve provides a remotely controlled, precise, and reproducible gas inlet for metering of the inert gas or lab air into the vacuum chamber. Thermally produced deformation of the valve's metal sealing surfaces determines the gas leakage rate which can be adjusted for gas flows as low as $10^{-10}$ mbar liter/second and as high as 600 mbar liter/second over the entire pressure range of the system. The valve is bakeable for UHV operation and virtually free of maintenance.

In addition to regulated inert gas back-fill while in vacuum conditions, the system was designed for inert gas environments at pressures greater than atmospheric, up to 1000 torr.

### 2.2.3 Pressure Measurement

The severe environment chamber's pressure/vacuum range requires a series of pressure gauges to accurately measure the extremely large pressure variations. Three gauges monitor the chamber vacuum pressure and one monitors the vacuum level in the pumping stack as shown in Figure 5. All four gauges are operated through a programmable controller. The type of gauge, principle of operation and useful pressure measurement range of the three types of gauges are shown in Table 1.

**Table 1. Vacuum Pressure Measurement Gauges**

| Gauge type | Principle of Operation | Pressure range ( Torr) |
|---|---|---|
| Capacitance Diaphragm | Capacitance changes due to deflections in a metal diaphragm | 1.0 to 1000 |
| Thermocouple | Heat loss from a wire filament | $10^{-3}$ to 760 |
| UHV Cold Cathode | Ionization of residual gases in a magnetron discharge | $10^{-11}$ to $10^{-2}$ |

Gauges were selected to have overlapping measurement ranges in order to accurately measure pressures from above atmospheric to ultra-high vacuum. These gauges were chosen for their accuracy in this application as well as simplicity of use and minimal maintenance.

## 2.3 Thermal Simulation System

### 2.3.1 Quartz Lamp Heaters

Just as with the mechanical and atmospheric subsystems, the thermal stresses imposed on the specimen may be dynamic or cyclic. A UDRI designed four-zone quartz lamp heating and thermal control system was adapted for vacuum environment use to heat the specimen in four independent temperature zones [3,4]. This system was integrated with special computer software, which generates arbitrary thermal cycles and maintains the temperature at the four zones on the specimen to provide either extremely uniform spatial temperature fields or specified thermal gradients to simulate component service conditions.

The UDRI developed lamps are extremely compact and require only a 70 mm exposed specimen section between the grips. The lamps are shown in Figure 6. The four quartz bulbs are arranged in the liquid cooled lamp body such that two lamps can be placed in close proximity and transverse to the specimen's longitudinal axis. This horizontal specimen orientation isolates and minimizes thermal gradients across the shortest dimension of the specimen, i.e., the thickness.

The quartz-lamp heating system was designed for gas and liquid cooling, however, they are used without gas cooling while under vacuum conditions. Conventional quartz lamps which are exposed to the cooling effects of laboratory air are constructed of aluminum. To compensate for the loss of gas cooling and natural convection in a vacuum, lamp bodies for the severe service machine were machined from copper, to improve conduction and heat transfer to the liquid cooling medium. Heat generated by the quartz lamps also elevates the temperature of components within the chamber through conduction and radiation in vacuum conditions. Liquid cooling is used to remove excess heat in the lamp bodies, load train, and extensometer support. Metal sealed UHV rated VCR fittings are used exclusively for all liquid cooling connections

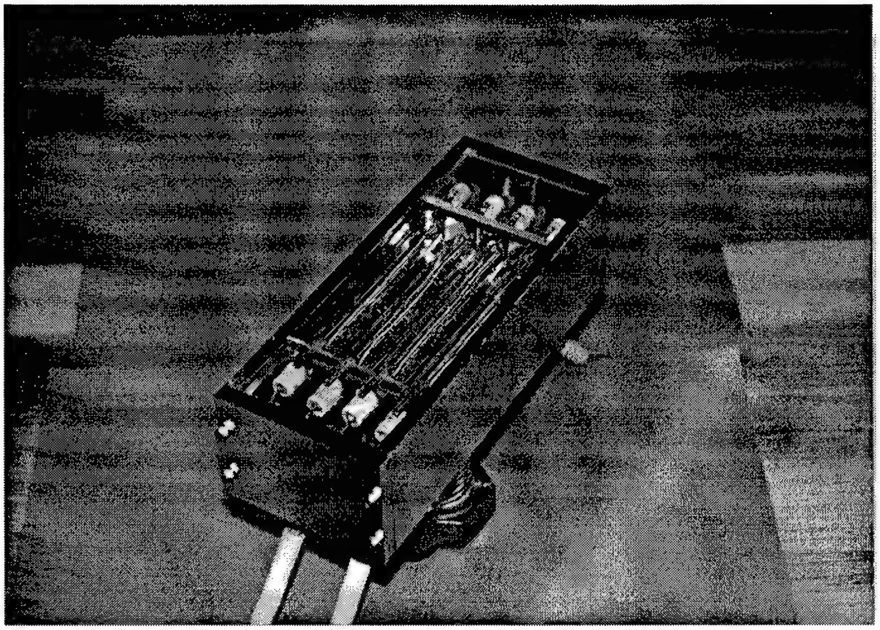

**Figure 6** Four-zone Quartz lamp heaters.

within the chamber to prevent internal coolant leaks and trapped gases.

The copper lamp bodies were nickel plated to prevent oxidation and provide a UHV rated finish and an inherent reflector for the quartz lamps. A UHV compatible lamp support was designed giving the lamps precision vertical motion for placement in close proximity to the specimen. The lamps are also retractable when not in use to allow access to the specimen.

Electrical power is routed to the quartz lamps through teflon insulated silver plated copper wire. The teflon insulation exhibits extremely low-outgassing properties in this application, and the silver plated copper wiring minimizes oxidation.

### 2.3.2 Four-Zone Temperature Measurement

The four zone temperatures are monitored with B, K, or S type thermocouples depending on the specimen test conditions. Ceramic insulated thermocouple wire was selected to minimize outgassing within the chamber. Thermocouples are attached to the individual temperature zones on the specimen with spotwelds or ceramic adhesive.

## 2.4 Data Collection and NDE

The ability to obtain as much useful data as possible from a given test enhances the characterization capability of a materials testing program. The UDRI has developed several tools to monitor material behavior including the adaptation of NDE techniques to mechanical testing. Using these techniques enables the researcher to collect extensive data regarding both the macroscopic and microscopic state of damage in the specimen under test. This behavior monitoring and data collection capability, combined with the dynamic simulation of mechanical and thermal stresses in a variety of atmospheric conditions, creates the ability to study damage mechanisms in great detail under precisely controlled conditions.

The incorporation of these techniques into a UHV chamber required some modifications to optimize the systems capability. Special care is given to the prevention of trapped gasses and minimization of outgassing, including the use of vacuum rated Kapton insulated signal wire.

### 2.4.1 Force Measurement / Load cell

A Sensotech stainless steel load cell was used inside the environmental chamber to accurately measure the forces applied to the specimen. Locating the load cell within the chamber allows the automated control system to maintain the commanded loads on the specimen during chamber pressure excursions. The stainless steel load cell body was modified with the addition of venting ports to prevent trapped gases and the building of pressure in the load cell.

### 2.4.2 Strain Measurement / Extensometry

A standard MTS model 632.53F-04 elevated temperature extensometer was chosen to measure specimen displacement and strain. Although special vacuum-rated units are available, they were deemed unacceptable for this application due to their significantly greater cost and complexity. The extensometer uses quartz rods to contact the specimen with low force, has a 12 mm gage length, and ±2.40 mm travel. This extensometer has proven to operate reliably in elevated temperature vacuum environments. The addition of liquid cooling to the support bracket protects the instrumentation and electronic circuitry from radiant heat produced by the quartz lamps.

### 2.4.3 Nondestructive Evaluation

Included in the instrumentation and data acquisition system was the ability to study complex material systems with *in situ* active ultrasonics. This system transmits ultrasonic pulses through the specimen in the form of surface and/or bulk waves and records how the signal is modified as it passes through the material. Preliminary studies performed by the UDRI [5] have

shown the ability to monitor CMC and MMC matrix cracking during initial loading as well as measure subsequent degradation.

The system used to generate, receive, and digitize the ultrasonic signals consists of a microcomputer with an analog to digital converter for digitization of the ultrasonic signal, and a pulser-receiver to excite and receive the response of the surface wave transducers. A broadband JSR 35 MHz ultrasonic pulser-receiver sends electric pulses to the transducers to generate ultrasound. The Panametrics ultrasonic transducers have a center frequency of 10 MHz, a diameter of 0.25 inch, and attach to specially machined wedges to produce surface waves with a velocity of 3.06 mm/usec in titanium. The signals produced by the receiving transducer are digitized by a Signatec 500 MHz 8-bit A/D signal processing system. The A/D board resides in a personal computer, and has pretrigger and external trigger capability.

The *in situ* surface acoustic wave ultrasonic technique was originally developed by UDRI and this hardware was specifically selected for use within the dynamic range and conditions of the environmental simulation system.

## 2.5 Test System Automation and Control

The UDRI developed Materials Automation and Test Environment (MATE) software was chosen to automate the test system. The appropriate hardware and software items were assembled to allow MATE to control the mechanical, thermal, and atmospheric environment of the specimen as arbitrary functions of time. This automation and control capability provides a means of conducting both baseline tests to determine damage mechanisms as well as service simulation tests to verify models and predict component service lives.

The MATE system was originally designed with a flexible software and hardware architecture. This flexibility allows the researcher to use existing test methods in new ways or develop new methods based on combinations of existing ones. In addition, new measurement technologies can be incorporated in the MATE system relatively easily, by modifying existing program modules.

The MATE software system consists of a main shell program and supporting modules that perform various tasks. The modules are arranged in a series of menus according to the associated mechanical test type. For example, modules for performing crack propagation tests using CMOD compliance and back face strain are listed in one menu along with modules for crack growth rate and crack closure analysis. The test control and data analysis modules allow the operator to control a wide variety of variables associated with the task at hand. For example, the crack propagation test control module MCTEST provides access to over 100 test control, data presentation, and data analysis variables. To provide maximum flexibility without overwhelming the operator with details, the MATE system uses a graphical interface with a simplified data entry and menu selection strategy.

The MATE system is designed to run on a microcomputer, an excellent hardware platform for automation of advanced research tasks. A wide variety of compatible accessory boards are available at low cost to meet almost any data acquisition, communication, or data display needs that may arise in a research laboratory.

# Section 3
## *System Capabilities*

The test system detailed in this report was designed to simulate the dynamic mechanical and thermal stresses with varying atmospheric conditions found in high-performance aerospace service histories. This system can impose on a specimen the conditions that an aerospace vehicle transitioning from earth to earth orbit and returning would experience. The inherent flexibility of the simulation and automation systems provides the means to conduct both baseline tests to study the degradation due to a specific condition, or arbitrary combinations of conditions to accurately simulate service histories.

The system can provide the conditions necessary to investigate the monotonic, fatigue, creep, or thermomechanical fatigue behavior of a given material. The automation and control hardware allows these tests to be conducted in load, strain, or stroke control. Data can be collected from instrumentation and nondestructive evaluation techniques to better characterize the materials behavior.

Specimens of up to 19 mm width can be clamped to in precisely aligned grips with up to 45 kN gripping force. The specimen, grips and load train can be precisely aligned to prevent unwanted bending stresses.

The dynamic simulation of severe-environment conditions is possible with each of the three subsystems. Mechanical stresses are induced in the specimen by a hydraulic actuator, capable of applying dynamic axial loads up to ±50 kN. The four-zone quartz lamps can heat the specimen to a uniform temperature or specified gradient of up to 1500°C. In addition to mechanical and thermal stresses, the atmospheric simulation system can operate over the range of positive pressure,1000 torr, to ultra-high vacuum, $10^{-9}$ torr. The vacuum chamber can be controllably back-filled to simulate inert gas environments, or atmospheric / vacuum cycles. The chamber can be evacuated to $9.9 \times 10^{-8}$ torr from atmospheric pressure in less than 30 minutes. The rapid vacuum pumping speed dramatically reduces setup time required to begin a materials test in a controlled vacuum environment.

## References


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The University of Dayton